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SPATIAL TELECOMMUNICATION AND GIS VIEWSHED ANALYSIS OF CELLULAR NETWORK TOWERS WITHIN NASARAWA TOWN

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ABSTRACT

Effective telecommunication is essential to the economic growth of any settlement. Spatial telecommunication, encompassing cellular networks, satellite communication, and wireless internet access, relies heavily on the strategic placement of cell towers/masts to ensure optimal signal coverage. Geographic Information Systems (GIS) offer powerful tools for analyzing these spatial relationships between the location of the towers and signal coverage. This study explores the synergy between spatial telecommunication and GIS viewshed analysis, a technique that identifies areas visible from a specific vantage point obtained by integrating viewshed analysis with other geospatial data which help telecommunication companies to optimize network design, minimize infrastructure costs, and bridge the digital divide in geographically challenging areas. It also uses GIS viewshed analysis to scrutinize the signal coverage of the four major telecommunication networks in Nasarawa town. The study area has seven districts namely Tammah, Gunki, Oversea, Cikin Gari (Main Town), Unguwan Biri, Student Village and Mangoro Goma in which at least three masts were identified and studied in each. The study used GPS field survey and On-Site questionnaire methods to gather data. The handheld GPS devices was use to pinpoint the exact locations of all the telecommunication towers in the study area. Interviews were conducted at each tower location to collect additional details about the towers themselves and their network operators. A total of twenty-two (22) telecommunication towers/mast belonging to four major telecommunication operators namely Mobile Telecommunications Network (MTN), Airtel, Globacom Limited (GLO) and 9Mobile (formerly Etisalat Nigeria) were identified and used for this study. Results shows that Globacom network towers were better spatially distributed with its signal covering 31% of the study area, followed by Airtel, MTN and 9Mobile with 26%, 23% and 20% respectively. Globacom produce the highest signal coverage due to a greater number of independent cellular network tower. Rural areas around Nasarawa town often lack access to quality telecommunication infrastructure. GIS analysis can identify underserved communities, guiding strategic telecommunication tower placement to bridge the digital divide and promote equitable economic opportunities. By examining Nasarawa as a study area, we were able showcase the transformative potential of GIS viewshed analysis in driving economic development and paving the way for a more digitally connected future. The study finally paved way for telecommunication tower optimization and efficient network coverage.

Keywords: Spatial Telecommunication, Viewshed Analysis, Network Coverage, cellular mast, Telecommunication tower.

INTRODUCTION

While Nasarawa possesses abundant resources like minerals and fertile land, economic growth is hampered by limited access to reliable telecommunication services. Analyzing optimal locations for base stations can significantly improve network coverage, fostering business development and entrepreneurship. The socio-economic growth of cities around the world is significantly influenced by telecommunication. In order to take advantage of telecommunications, numerous cities in developing nations across the globe are now extending their telecommunications infrastructures, particularly in the field of the global system of mobile telephony (GSM) (Idris et. al., 2023).

The need for communication between humans has been around for years, from the early days of carving on walls to sending messages by carrier pigeons, humanity has gone through many periods of evolution when it comes to telecommunications, from telegraph lines to 5G networks right now (Kiriparan, 2023). Therefore, this paper explores the synergy between spatial telecommunication and GIS view shed analysis, a technique that identifies areas visible from a specific vantage point. But however continuous deregulation of Information and Communication Technology (ICT) worldwide is observed majorly in the developing countries where development is yet to reach peek. A lot of literature on ICT infrastructure and its impact on economic growth and development are steadily increasing geometrically (Chukwu et.al., 2023).

Telecommunication infrastructure and mast locations ranging from the fixed costs of obtaining information and other variable costs that may be incurred in business (Norton, 2021). The ICT and its associated infrastructure improve; transaction reduces costs and increase output for various sectors of the economy and development (Röller & Waverman, 2020). As such business transaction in ICT including telecommunications and its associated infrastructure provide significant importance to the development of the entire gross domestic product of the economy. Moreover, in terms of the Network Readiness Index (NRI) published by the World Economic Forum (2021), developing countries continue to be far behind because of lack of constant power supply, Which implies that the competence of the developing economies to benefit efficiently from ICT developments is limited due to a lot of factors ranging from power supply, good roads and availability of good health facilities.

Recent discussions quoting from Len Waverman of the London Business School focus on how mobile phones, not expensive computers, are actually closing the digital gap (Economist, 2018). A study from Parker (2022), also highlights the expansion of wireless telecommunications and mast location in Africa countries bridging the gap between the developing countries and the industrialized world. This report finds that in 2004, sub-Saharan Africa, were having more new mobile phone subscribers than in the whole of North America due to the available market and acceptability. According to the World Bank findings only the private sector alone invested $230 billion in telecommunications and its associated infrastructure in the developing world between 1993 and 2003, and other countries with wellregulated and competitive markets are found to be their highest place of investment. Given these findings, it is important to study the synergy between telecommunications and economic growth, if Nigeria, specifically Nasarawa local government area in Nasarawa state will be of importance to developments in their economic growth.

Due to technological innovations, increased connectivity demands, and the evolution of communication networks, in recent years there have been significant changes and advancements in telecommunication towers. A notable change is the transition from 2G and 3G to 4G and now 5G networks. 5G networks require denser and more advanced infrastructure, including smaller cells and increased capacity, which has led to the deployment of more diverse types of telecom towers (Andreev, 2019). Cell towers can handle thousands of calls or internet connections at the same time. Cellular towers serve as the intermediary between mobile devices and the telecommunications network. They work by receiving signals from a mobile device, converting these signals into a digital format, and then sending them along to their destination, either to another phone or onto the internet.

Viewshed refers to the portion of land surface that is visible from one or more viewpoints and the process of deriving viewshed is called viewshed analysis or visibility analysis (Edan et.al., 2018). While the literature on ICT and its effects on growth is now considerably large, this paper explores the synergy between spatial telecommunication and GIS viewshed analysis, a technique that identifies areas visible from a specific vantage point obtained by integrating viewshed analysis with other geospatial data, telecommunication companies can optimize network design, minimize infrastructure costs, and bridge the digital divide in geographically challenging areas. Hence the study aims at using GIS viewshed analysis to analyze the signal coverage of the four major telecommunication networks in Nasarawa town.

Types of Telecommunication Towers

Telecommunication towers are a combination of steel and concrete structures such as, radio masts and towers, built primarily to hold antennas for telecommunications and broadcasting (Kiriparan, 2023). They also vary based on their construction, location, and the type of technology they use. Towers are generally categorized as Ground-based towers or Roof-top towers. In this study, only Ground-based towers were identified. Some of the common types are Lattice towers, Guyed towers, Monopole towers and Mobile towers Lattice towers (Figure 2) are freestanding and segmentally designed with rectangular or triangular base steel lattices. This type of tower is the most common in the study area (Figure 4). This tower is stronger than Guyed and monopole towers area (Figure 3), they can support more equipment and reach greater heights. Lattice towers feature a framework of horizontal and diagonal rods creating a lattice effect.

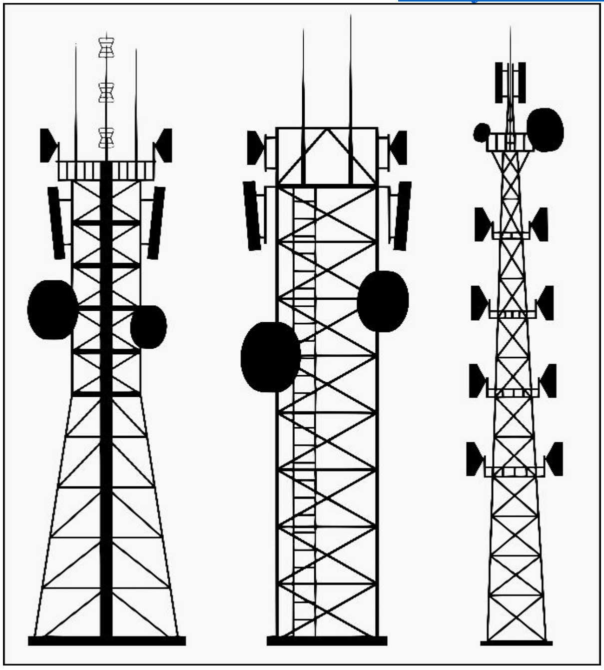

Figure 2: Examples of Lattice towers (Source: Adopted from Ubani, 2023).

A Guyed tower use guy-wires for stabilization. It is the lightest and most cost-effective cell tower to construct, but it require a large amount of space as the guy-wires extend from the tower to the ground at a considerable distance. Guyed towers are typically used in rural areas where space is less of a concern. A monopole tower is a single, freestanding pole that typically stands between 15-60 meters tall. The antennas are usually located at the top inside a canister or are mounted on the exterior. Mobile cell towers also-know-as tower-on-wheels or cell-on-wheels are considered low-profile and portable because they are often mounted on trailers. They are often used in temporary or emergency situations; they are also useful if budget or permits are of concern.

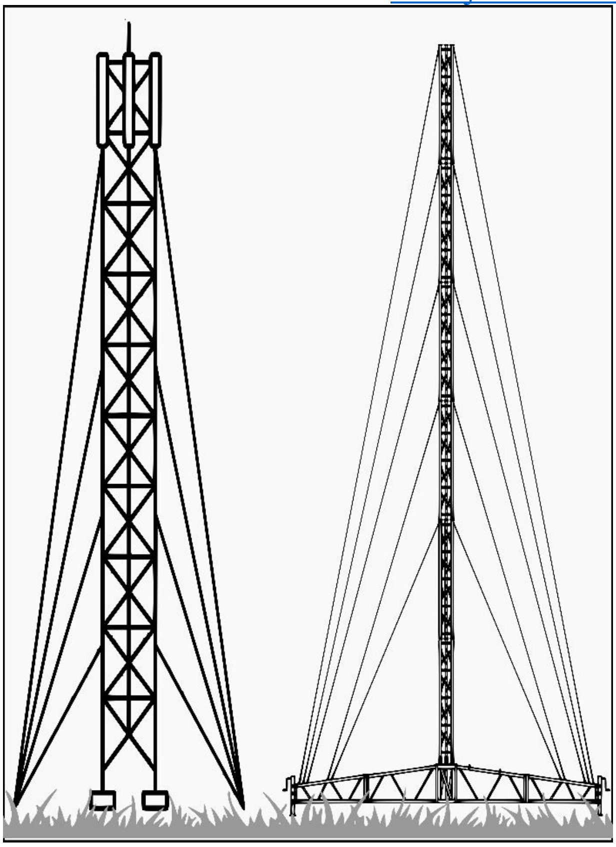
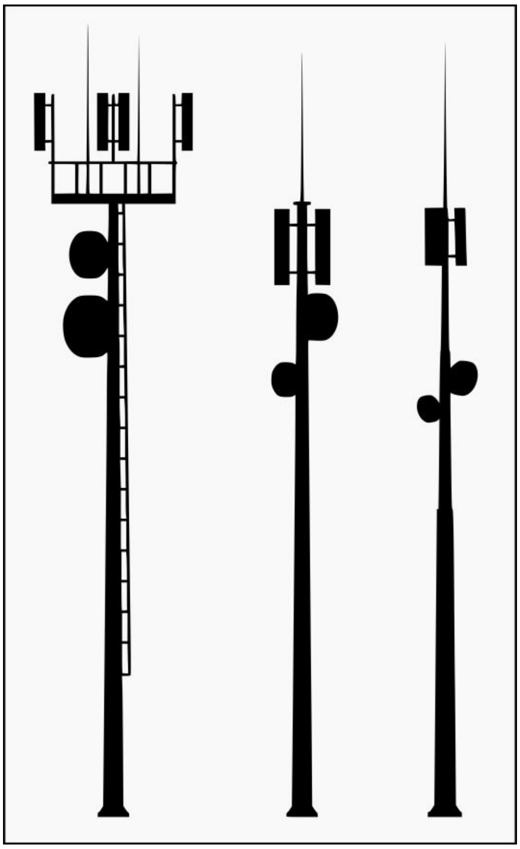

Figure 3: Examples of Guyed tower and monopole tower (Adopted from Ubani, 2023).

Cellular Tower Components

The components of a tower may vary depending on the coverage needed and traffic density in the specific area it serves. The following components are typically present in most installations: Antennas (Panel Antennas or Sector Antennas), Base Transceiver Station (BTS), Tower or Mast, Ground-Based Equipment, Microwave Dishes and Cabling.

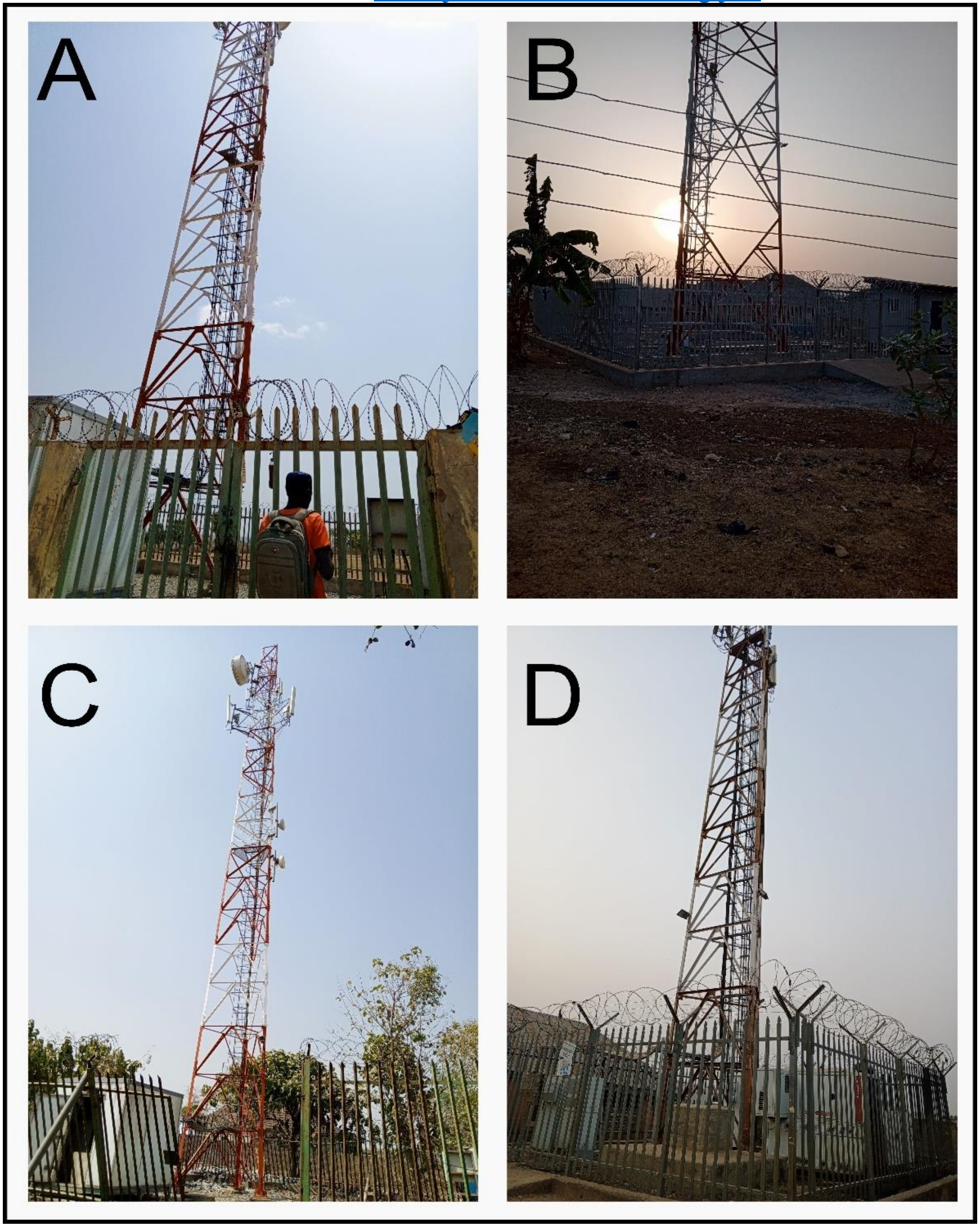

Figure 4: Some telecom towers identified in the study area. (A) Globacom tower in front of Old ICT Block, FPN at Tammah, (B) MTN and Airtel tower at Student Village, (C) Airtel tower Opposite Al-Iman School at Unguwan Biri, (D) Shared MTN and 9Mobile tower located at the Back of Nasarawa MotorPark, Cikin Gari (Main Town). (Source: Authors' field data collection).

MATERIALS AND METHODS

The study area has seven districts namely Tammah, Gunki, Oversea, Cikin Gari (Main Town), Unguwan Biri, Student Village and Mangoro Goma in which at least three masts were identified and studied in each. The major data source for this study was primary which was sourced using GPS field survey and On-Site questionnaire methods. The only secondary data we used was the Digital Elevation Model (DEM) of 30m resolution by 'Shuttle Radar Topography Mission (SRTM)' accessed via OpenTopography.org, a data facility focused on high-resolution topographic data, and related tools and resources.

The Study Area

The study area is composed of three political wards of Nasarawa East, Nasarawa Central and Nasarawa Main-town. It lies between latitudes 08° 30'N and 08° 36'N North and longitudes 07° 40'E and 07° 45'E East of the Greenwich meridian.

Nasarawa town, situated in Nasarawa LGA within Nasarawa state of Nigeria's north central region, presents a compelling case study for exploring the economic impact of telecommunication infrastructure.

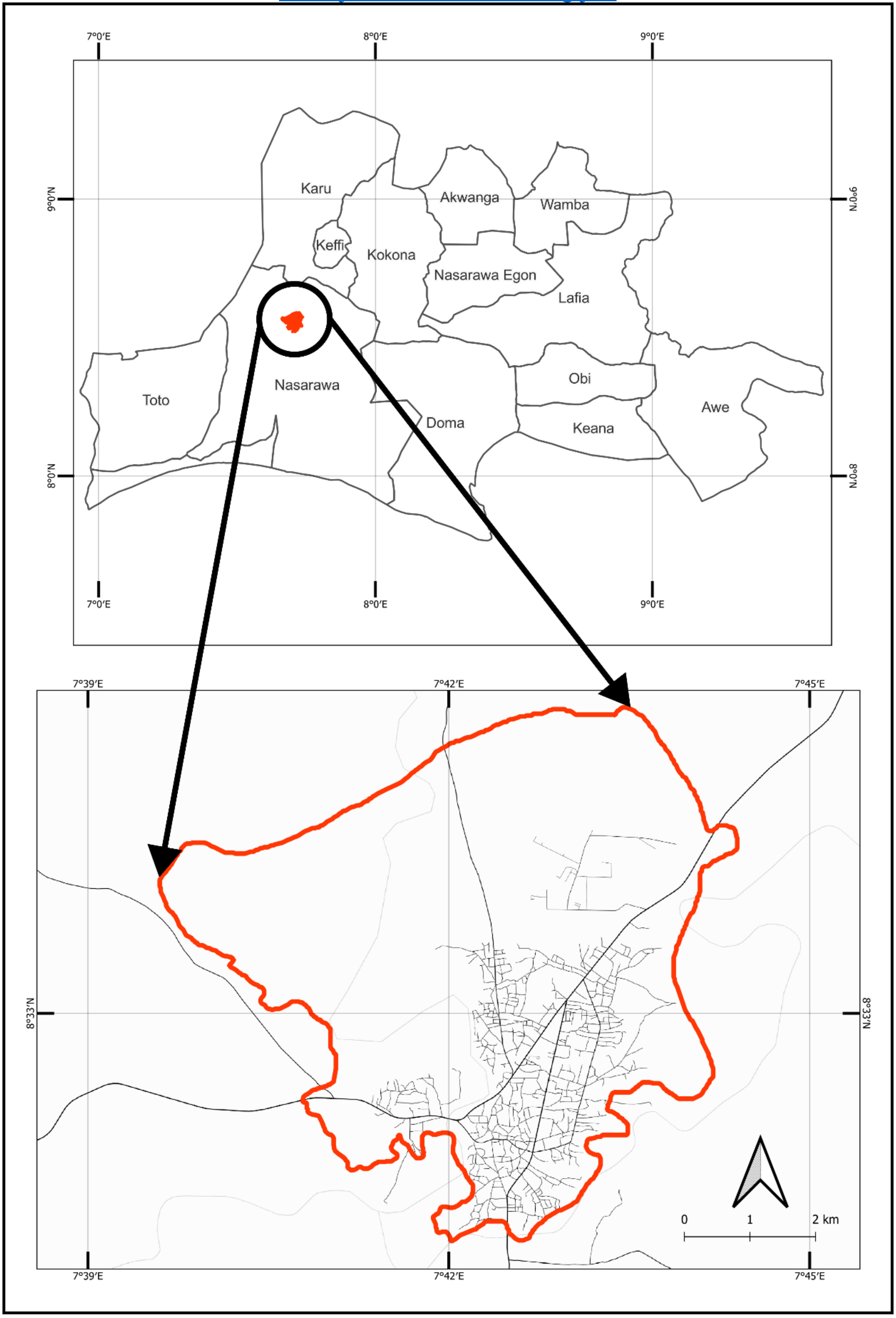

Figure 1: Map of the Study Area (Source: Authors' work).

Nasarawa town boasts a varied landscape - from the floodplains of the Benue River in the south to the rolling hills and dissected terrain further north. This diversity creates challenges for traditional network planning methods, making GIS viewshed analysis particularly valuable. By examining Nasarawa as a study area, researchers can showcase the transformative potential of GIS viewshed analysis in driving economic development and paving the way for a more digitally connected future. The above is the map of Nasarawa State where the map of Nasarawa LGA was extracted to show the study area and position of various telecommunication towers owned by different service providers.

Data Collection Process

Both Primary and Secondary data were collected for this study. The primary data was collected using the Hand held Global Positioning System (GPS). The Hand held was used to obtain the coordinates of the towers location alongside with the distribution of questionnaires to know the service providers of each of the telecommunication towers within the study areas. The coordinates were picked when the expected position error (EPE) drops to less than plus or negative Four Meters for more precise data. The attribute and spatial data collected are shown in Table 2.While the only secondary data collected was the Digital Elevation Model (DEM) of 30m resolution of the study area was obtained through Shuttle Radar Topography Mission (SRTM) accessed via Open Topography.org. The data collected were imported into the viewshed analysis in QGIS.

Viewshed analysis in QGIS:

Telecommunication signal obeys the law of rectilinear propagation and this needs unobstructed visibility to get to the intended destination with optimal strength (Edan et.al., 2018). We used the "Visibility Analysis Plugin" in QGIS to analyze the signal coverage of the twenty-two (22) telecommunication towers out of which nineteen (19) were owned by single network operator and three (3) had multiple/shared network .The figure 5 show the towers with single and multiple/shared network operators.

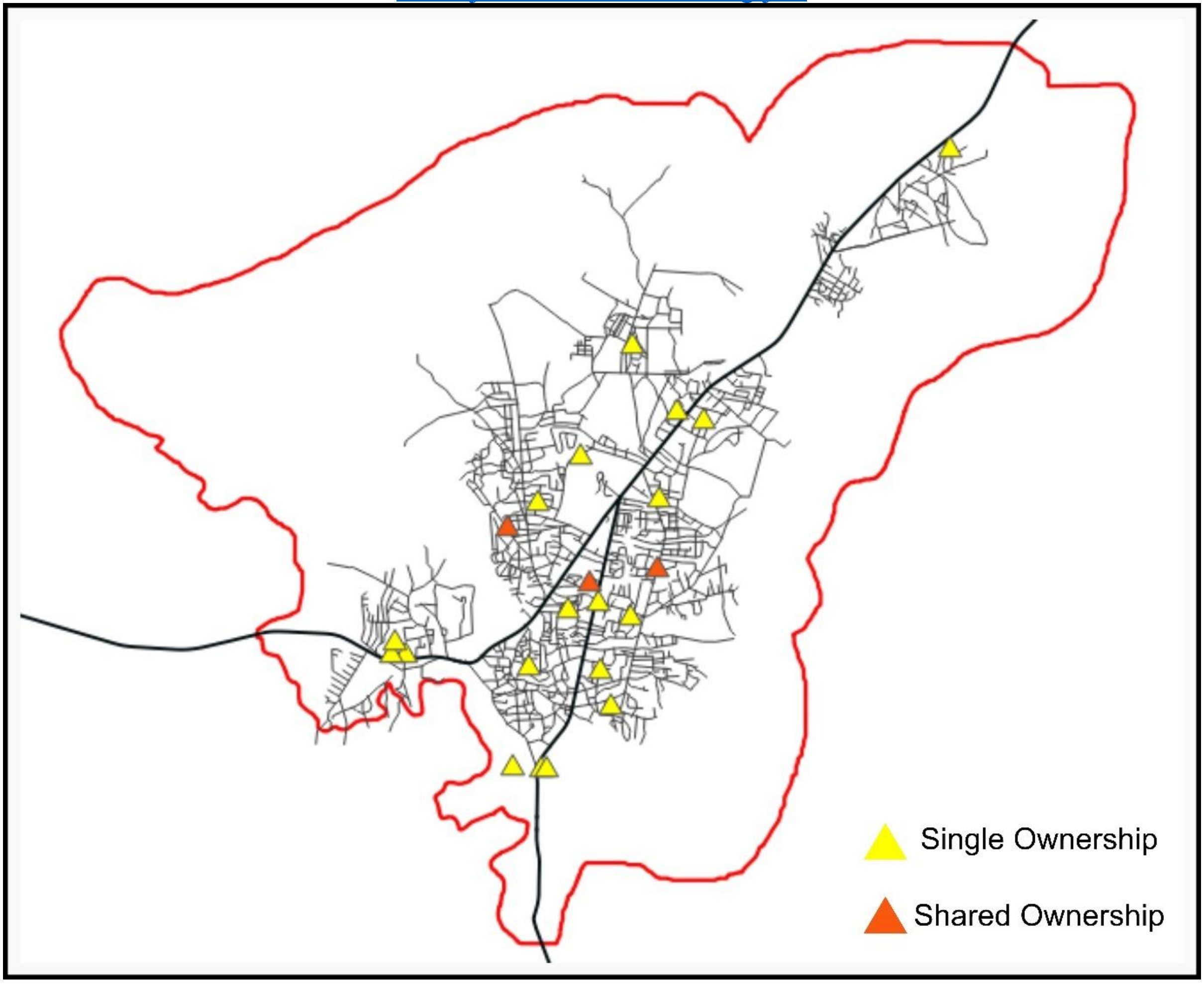

Figure 5: Show the towers with single and multiple/shared network operators (source: Authors' analysis)

The steps we followed for generating a viewshed from raster elevation data are outlined in Figure 6 below;

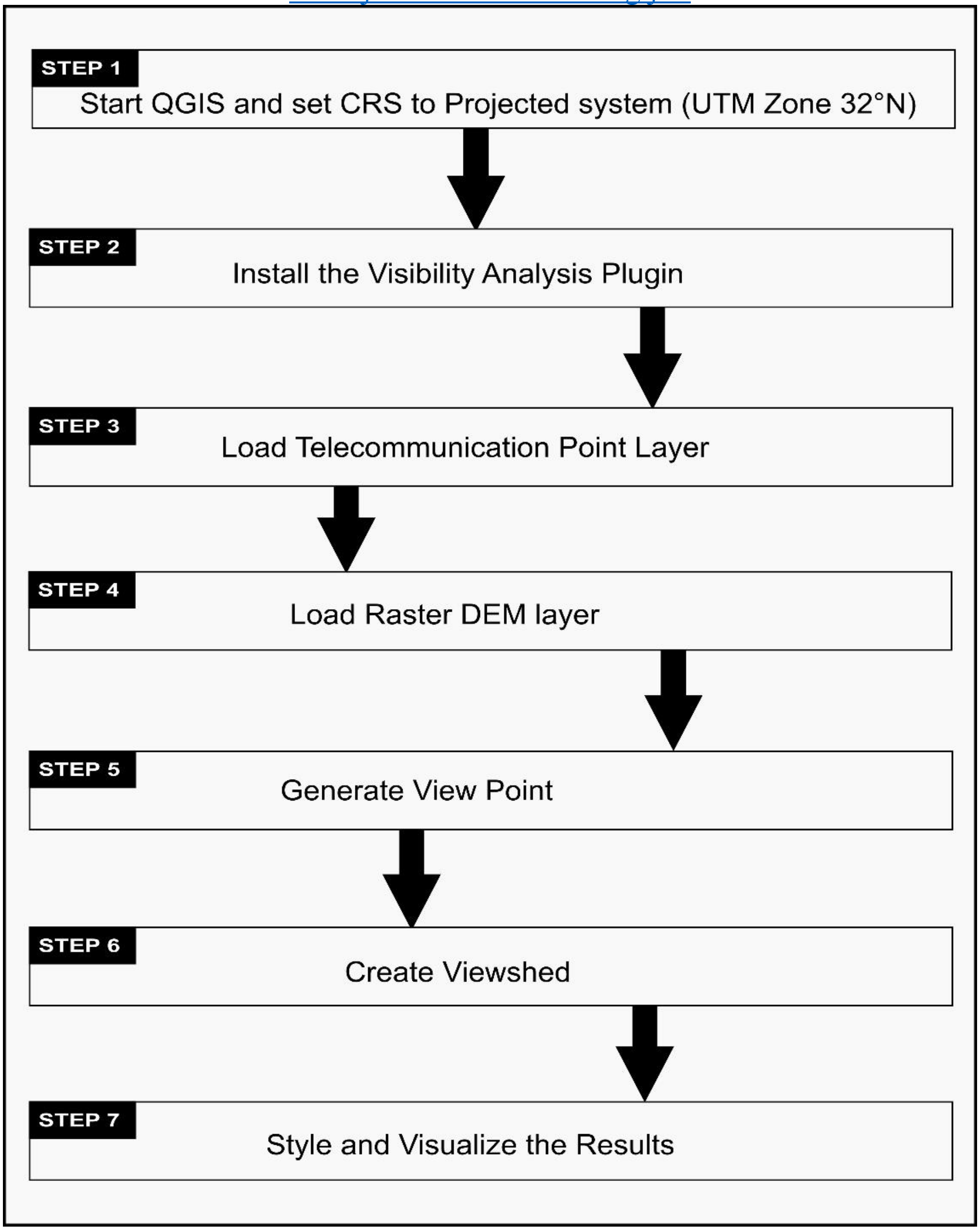

Figure 6: Algorithm for creating Viewshed in QGIS (source: Authors' analysis)

The first step is to "Start QGIS project and set the coordinate reference system (CRS) to Projected system. For this study, the projected coordinate system used was 'UTM Zone 32°N'. The CRS must be a projected system because GIS viewshed analysis involves distance calculations which are best done using a projected CRS. Hence, we reprojected the DEM to match the project CRS.

The next step was to Install the 'Visibility Analysis' plugin. By default, as of QGIS version 3.32.3-Lima, 'Visibility Analysis' plugin doesn't come with the initial installation so we installed it separately.

Next, we prepare the vector and raster datasets. The vector data was the "Telecommunication Point Layer" we collected earlier using GPS field-survey. And the raster was the SRTM "DEM layer" downloaded from OpenTopography.org. These two layers were loaded in the QGIS project based on the projected CRS.

We then converted the vector point layer into "View Point" that will be used to create the "Viewshed" raster (Figure 7). The last step was to "Style and Visualize the Results". The resulting raster layer can be subjected to further raster analysis, such as calculating the area covered by each viewshed pixels.

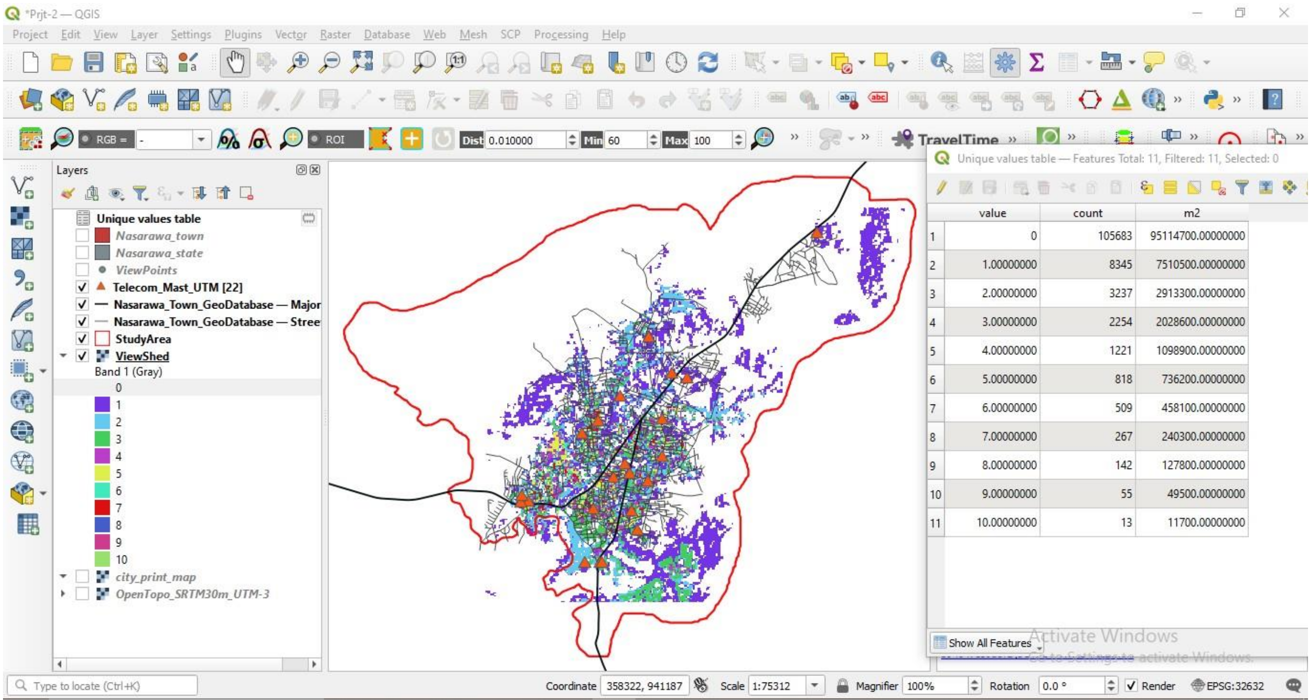

Figure 7: The viewshed results in QGIS (source: Authors' analysis)

RESULTS AND DISCUSSION

Airtel has five (5) towers one of which is a shared tower. MTN has eight (8) towers three of which are shared towers. Globacom also has eight (8) towers one of which is a shared tower. Finally, 9Mobile has five (5) towers two of which is a shared tower.

Table 1: Number of Telecommunication by network operator

S/N	Network Operator	Single Tower	Shared Tower	Number of Towers
1.	Airtel	4	1	5
2.	MTN	5	3	8
3.	Globacom	7	1	8
4.	9Mobile	3	2	5

Table 1a: Percentages and Pie chart from calculated viewshed Areas for the four network provider towers

S/N	Network Operator	Area (Ha)	Percentages of Areas	Pie Chart
1	Airtel	806.04	26%	94^{0}
2	MTN	714.96	23%	82^{0}
3	Globacom	958.41	31%	112^{0}
4	9Mobile	628.47	20%	72^{0}
5	**Total**	**3107.88**	**100%**	**360^{0}**

The Table 1a was extracted from Table 4 in other to calculate Percentage coverage using the Network area of coverage and also analyses it using a pie chart. Refer to Table 1a and Figure 9.

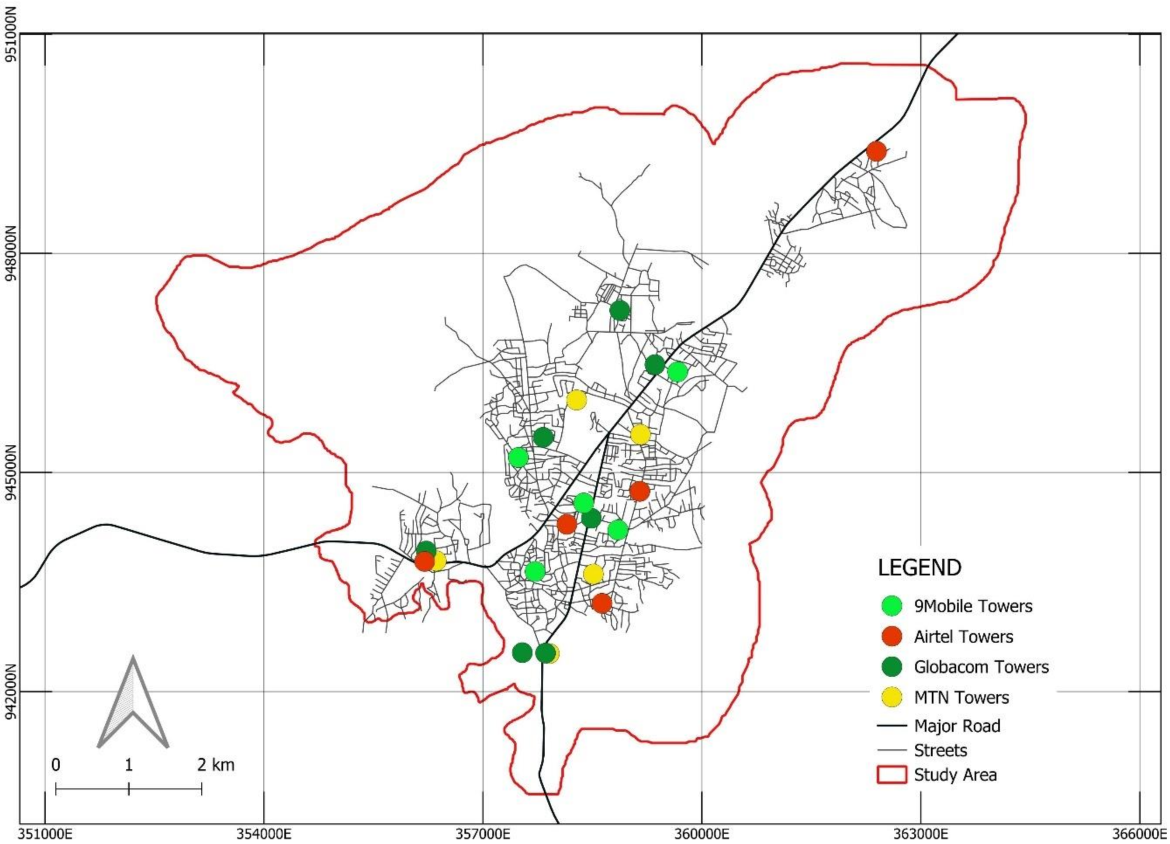

Figure 8: Spatial distribution of the towers (source: Authors' analysis)

The area covered by the raster DEM used for this study is 110289600m² (11028.96Ha). Results shows that Globacom network towers were better spatially distribute with its signal covering 31% (Table 1a &Figure 9) of the study area with the size of 958.41Ha, followed by Airtel, MTN and 9Mobile with 806.04Ha (26%), 714.96Ha (23%) and 628.47Ha (20%) respectively.

In a sparsely populated environment like rural areas, a cell tower can send signals to phones up to 30km away. In densely populated cities with many physical obstructions like buildings, the range might be reduced to a kilometer or two.

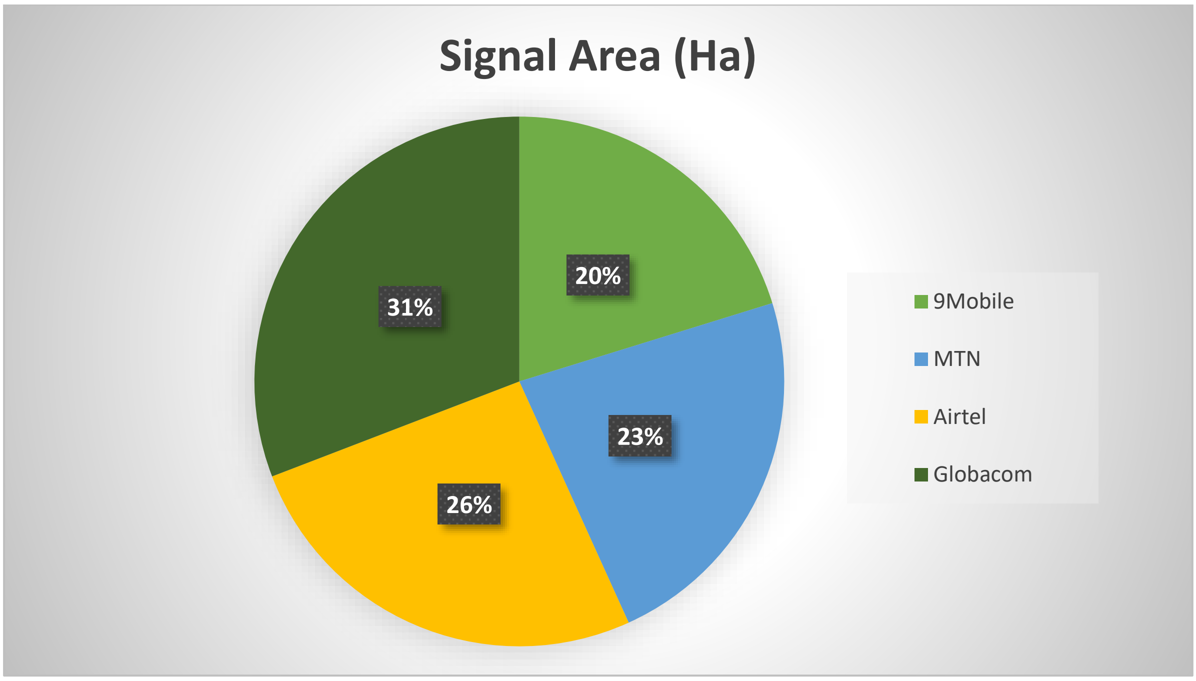

Figure 9: Signal coverage of the four major network (source: Authors' analysis)

Table 2: Telecommunication tower/mast data collected for this study

id	Location	Network Operator(s)	District	Latitude	Longitude	Easting	Northing	Network Ownership
1	End of Gunki, behind filling station	Airtel	Gunki	8.586814	7.749547	362394.797	949396.212	Single
2	Back of MotorPark	MTN and 9Mobile	Cikin Gari (Main Town)	8.543143	7.713237	358382.263	944580.267	Shared
3	Opposite Asasu Mosque	MTN	Unguwan Biri	8.535925	7.694894	356360.451	943788.853	Single
4	Student Village Junction	Globacom	Student Village	8.541259	7.714193	358486.838	944371.579	Single
5	Behind Old Grave Yard (Opp. Goat Market)	Airtel	Cikin Gari (Main Town)	8.540499	7.711147	358151.234	944288.621	Single
6	Opp. Al-Iman School	Airtel	Unguwan Biri	8.535848	7.693451	356201.582	943780.838	Single
7	Old ICT Block, FPN	Globacom	Tammah	8.567018	7.717657	358877.623	947218.725	Single
8	Opp. Government Science School	Globacom	Unguwan Biri	8.537128	7.693658	356224.846	943922.269	Single
9	New Mast at Shagari road	MTN and Airtel	Student Village	8.544616	7.72021	359150.356	944740.59	Shared
10	Tammah	Globacom	Tammah	8.560315	7.722054	359359.118	946475.843	Single
11	Tammah	9Mobile	Tammah	8.559424	7.724872	359668.989	946376.382	Single
12	Shagala	MTN	Tammah	8.551652	7.720283	359161.038	945518.563	Single
13	Back of Governe	MTN	Tammah	8.555901	7.712307	358284.641	945991.316	Single

	nt College							
14	Water Board	MTN, Globacom and 9Mobile	Oversea	8.548748	7.705089	357487.467	945202.987	Shared
15	Oversea	Globacom	Oversea	8.551265	7.708166	357827.146	945480.18	Single
16	Student Village	9Mobile	Student Village	8.539822	7.717506	358851.053	944211.432	Single
17	GRA	MTN	Cikin Gari (Main Town)	8.534348	7.714472	358515.048	943607.251	Single
18	GRA Extension	Airtel	Cikin Gari (Main Town)	8.530729	7.71555	358632.395	943206.648	Single
19	Unguwan Dallatu	9Mobile	Cikin Gari (Main Town)	8.534643	7.707214	357716.171	943642.505	Single
20	Unguwan Palaka	Globacom	Mangoro Goma	8.524591	7.705652	357540.54	942531.505	Single
21	Mangoro Goma	Globacom	Mangoro Goma	8.524551	7.708548	357859.319	942525.991	Single
22	Mangoro Goma	MTN	Mangoro Goma	8.524495	7.709001	357909.159	942519.636	Single

Source: Authors' Fieldwork Report, 2024.

Table 3: Calculated Viewshed Area for all cellular towers

Pixel value	Pixel count	Area (m^2)	Area (Ha)	Remarks
0	105683	95114700	9511.47	Locations receiving telecom signals from zero or no tower
1	8345	7510500	751.05	Locations receiving telecom signals from at least 1 tower
2	3237	2913300	291.33	Locations receiving telecom signals from at least 2 towers
3	2254	2028600	202.86	Locations receiving telecom signals from at least 3 towers
4	1221	1098900	109.89	Locations receiving telecom signals from at least 4 towers
5	818	736200	73.62	Locations receiving telecom signals from at least 5 towers
6	509	458100	45.81	Locations receiving telecom signals from at least 6 towers
7	267	240300	24.03	Locations receiving telecom signals from at least 7 towers

8	142	127800	12.78	Locations receiving telecom signals from at least 8 towers
9	55	49500	4.95	Locations receiving telecom signals from at least 9 towers
10	13	11700	1.17	Locations receiving telecom signals from at least 10 towers
Total		110289600.00	11028.96	

Source: Authors' Analysis

Table 4: Calculated Viewshed Area for the four network provider towers

Network	**Pixel value**	**Pixel count**	**Area (m²)**	**Area (Ha)**	**Remarks**	**Signal Areas (Ha)**
9Mobile	0	115561	104004900	10400.49	Locations receiving telecom signals zero or no tower	
9Mobile	1	4829	4346100	434.61	Locations receiving telecom signals from at least 1 tower	
9Mobile	2	1564	1407600	140.76	Locations receiving telecom signals from at least 2 towers	
9Mobile	3	506	455400	45.54	Locations receiving telecom signals from at least 3 towers	
9Mobile	4	84	75600	7.56	Locations receiving telecom signals from at least 4 towers	628.47
MTN	0	114600	103140000	10314	Locations receiving telecom signals zero or no tower	
MTN	1	5721	5148900	514.89	Locations receiving telecom signals from at least 1 tower	
MTN	2	1607	1446300	144.63	Locations receiving telecom signals from at least 2 towers	
MTN	3	519	467100	46.71	Locations receiving telecom signals from at least 3 towers	
MTN	4	85	76500	7.65	Locations receiving telecom signals from at least 4 towers	
MTN	5	11	9900	0.99	Locations receiving telecom signals from at least 5 towers	
MTN	6	1	900	0.09	Locations receiving telecom signals from at least 6 towers	714.96
Airtel	0	113588	102229200	10222.92	Locations receiving telecom signals zero or no tower	
Airtel	1	8280	7452000	745.2	Locations receiving telecom signals from at least 1 tower	

Airtel	2	674	606600	60.66	Locations receiving telecom signals from at least 2 towers	
Airtel	3	2	1800	0.18	Locations receiving telecom signals from at least 3 towers	806.04
Globacom	0	111895	100705500	10070.55	Locations receiving telecom signals zero or no tower	
Globacom	1	7966	7169400	716.94	Locations receiving telecom signals from at least 1 tower	
Globacom	2	2084	1875600	187.56	Locations receiving telecom signals from at least 2 towers	
Globacom	3	541	486900	48.69	Locations receiving telecom signals from at least 3 towers	
Globacom	4	58	52200	5.22	Locations receiving telecom signals from at least 4 towers	958.41
					Total	**3107.88**

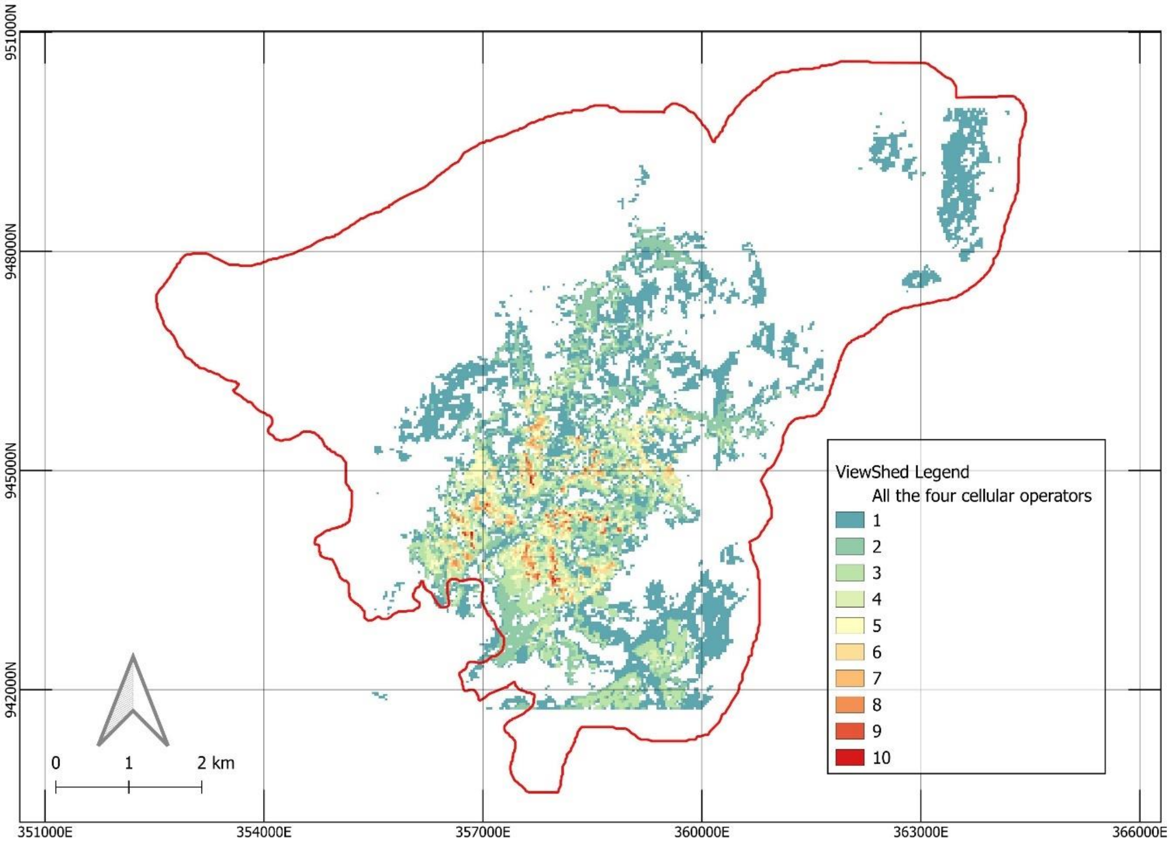

Figure 10: Viewshed analysis of all the networks (source: Authors' analysis)

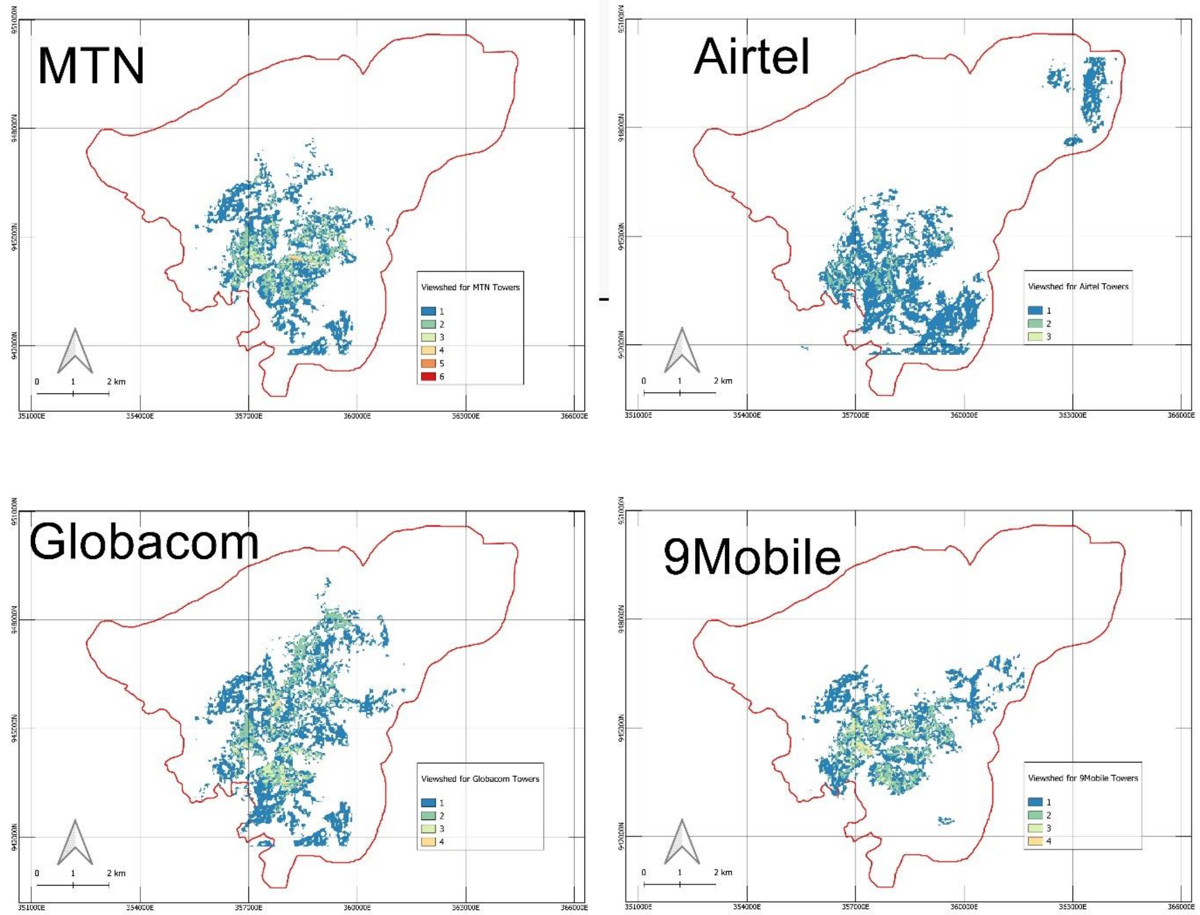

Figure 11: Viewshed analysis individual network (source: Authors' analysis)

Finally, figure 11 shows the different Network coverage of four service provider in Nasarawa LGA using shade. The shaded portion represents area of Network coverage, while the unshaded area represents area without Network coverage. MTN has 23% of the shaded area with Network coverage and 77% unshaded area without Network within the study area as shown above. Airtel has 26% of the shaded area with Network coverage and 74% unshaded without Network. Globacom has the highest shaded portion with 31% Network coverage and only 69% unshaded without Network coverage. 9Mobile has 20% Network coverage and 80% of the study area without Network.

The significance of this study shows the current extent of the signal coverage from the four Network providers, that is, Airtel, MTN, Globacom and 9Mobile in the study area as shown in figure 11. It also revealed areas without Network coverage that needed optimization by the various service providers and this could also result to a further research topic "Optimization of telecommunication towers for efficient Network coverage in Nasarawa town, Nasarawa LGA, Nasarawa State".

CONCLUSION AND RECOMMENDATION

This study has shown that the present locations of telecommunication towers or masts are not suitable placed for extensive signal coverage within the study area. As none of the four studied telecommunication operators has more than 50% signal coverage in Nasarawa town, as shown in Figure 9.0 and Table 1a.The highest was Globacom with 31%. This may be due to obstruction of signals after striking large building because of concentration within the metropolis, as such telecommunication towers are supposed to be sited away from metropolis to have access to wider coverage or additional towers may be sited for more network coverage or optimization

Globacom has wider signal coverage in Nasarawa due to the fact that it produces the highest number of independent towers (7), follow by MTN (5), Airtel (4) and 9Mobile (3). In fact, with this reason cellular network providers should strictly ensure that more cellular network towers be establish in densely populated area mostly urban centers or metropolis than rural areas with sparsely population which may not require many cellular network towers, and signals can also be received within a radius of thirty kilometer (30km). Most especially with the new advancements and the transition from 2G, 3G and 4G to 5G network. A research gap has been created with the availability of 5G network, other researchers should look into the speed of the network and make comparison with the current available 2G ,3G, and 4G. Lack of access to quality telecommunication infrastructure was heavily noticed in rural areas around Nasarawa town.

This study can be utilized to identify underserved communities, guiding strategic infrastructure placement to bridge the digital divide and promote equitable economic opportunities.

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